Radiation Levels and Activation at the ILC Positron Source

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- FLUKA model of positron source
- FLUKA results for undulator based and conventional positron sources
- Influence of electric field
- Summary

Source Model and Primary Beam

Primary Beams

	conv.	undul. I	undul. II
E_{e^-}, GeV	6.2	150	250

- Beam radius of 0.35 mm
- No beam divergence

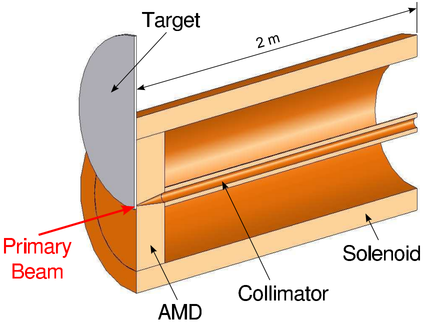
Target

	conv.	undul.
Thickness	4.5 X_0 (1.54 cm)	0.4 X_0 (1.535 cm)
Compounds	W 75 %	Ti 90 %
	Re 25 %	Al 6 %
		V 4 %

Capture Section (Copper)

- Adiabatic Matching Device (AMD)
- Solenoid
- Collimator

Source Model



Magnetic Field

For $0 < z < L$:

$$B_z(z) = \frac{B_0}{1 + g \cdot z},$$

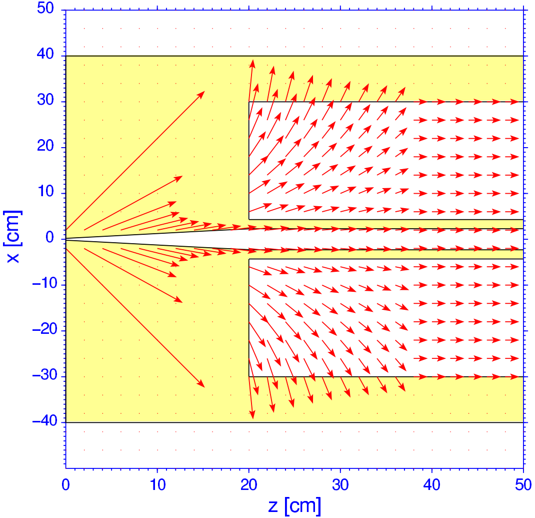
where

	Undul.	Conv.
B_0, T	6	6
g, m^{-1}	30	60
L, cm	36.7	18.8

For $L < z < 2$ m:

$$B_z = B_{sol} = 0.5 \text{ T}$$

No electric field!

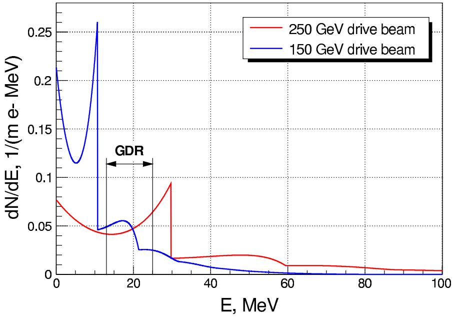


Energy Distribution of Photons

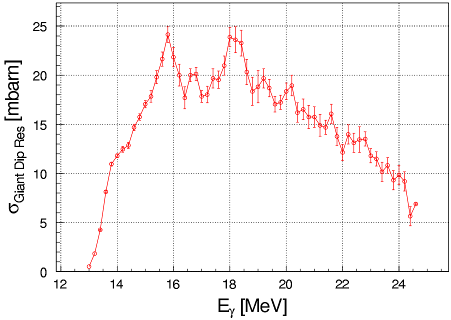
Undulator

$\lambda_u = 1$ cm
$B = 1.07$ T
$K = 1$

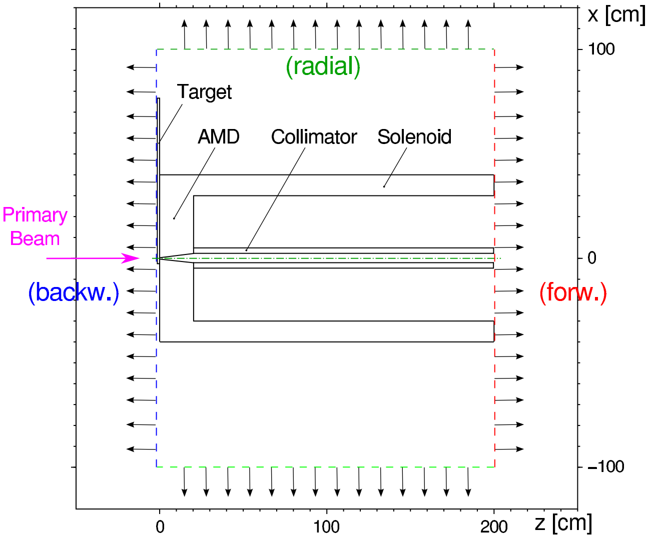
Energy Distributions of γ



Neutron Production:
Cross Section of **G**iant **D**ipole **R**esonance in ^{46}Ti



Definition of Calculated Fluxes



Positron Yield and Required Undulator Length

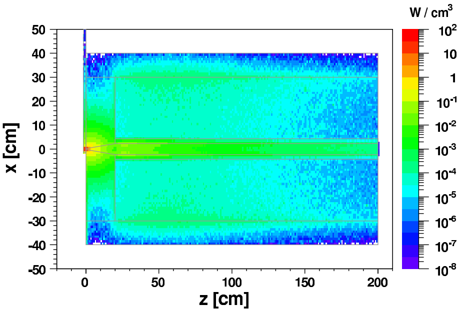
Source type	conv.	undul. I	undul. II
Primary electron beam energy, GeV	6.2	150	250
Required number of positrons at IP, e^+/s	2.82E+14 (2E+10 e^+/bunch)		
Required number of positrons at the end of pre-accelerator, e^+/s	4.23E+14 (50 % safety factor)		
Positron capture efficiency, %	11.5	35	
Convertion target positron yield	14.42 e^+/e^-	2.57E-2 e^+/γ	7.52E-2 e^+/γ
Required primary e^--beam, e^-/s	2.55E+14	2.82E+14	
Number of photons, $\gamma/(e^-\ m)$	–	2.575	
Required undulator length, m	–	64.72	22.14

Beam Power and Energy Deposition

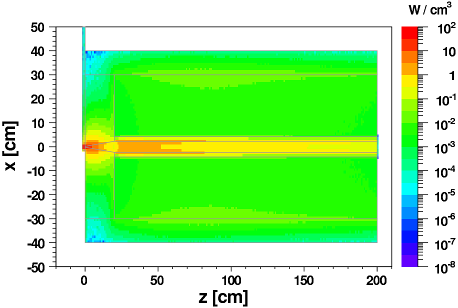
Source type	conv.	U150	U250
Primary beam power, kW	253.1	90.2	85.7
Photon beam power (forw.), %	17.40	82.06	80.45
Electron beam power (forw.), %	3.40	1.81	2.90
Positron beam power (forw.), %	3.16	1.10	2.34
Energy deposited in target, %	19.09	8.01	4.67
Energy deposited in AMD, %	19.40	5.70	5.97
Energy deposited in collimator, %	33.75	0.66	3.02
Energy deposited in solenoid, %	3.17	0.07	0.30
	99.38	99.41	99.66

Deposited Energy Density

Undulator Based Source (150 GeV)

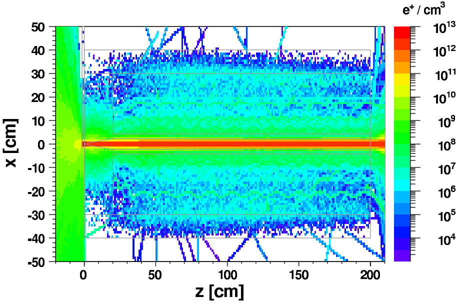


Conventional Source

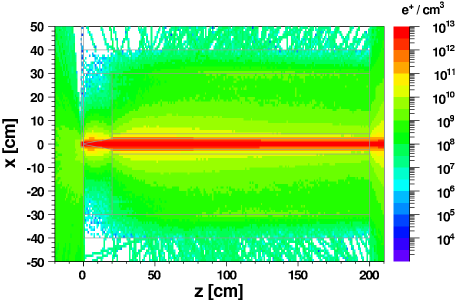


Positron Density

Undulator Based Source (150 GeV)

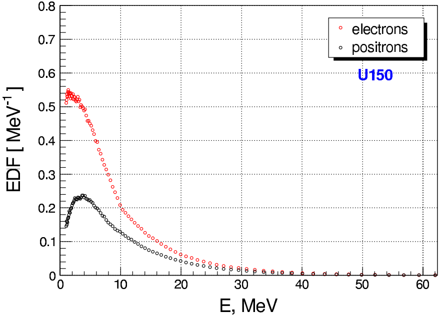


Conventional Source

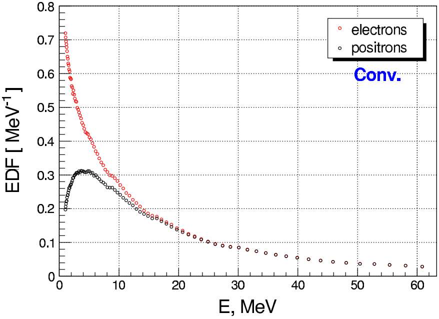


Energy Distributions of Electrons and Positrons
(after the target; norm. on 1 e^+ at IP)

Undulator Based Source (150 GeV)

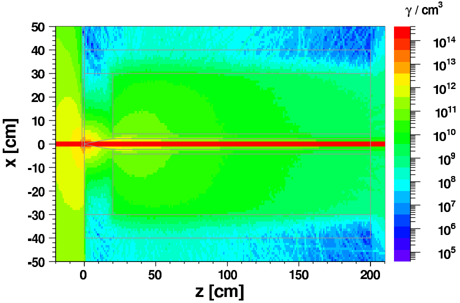


Conventional Source

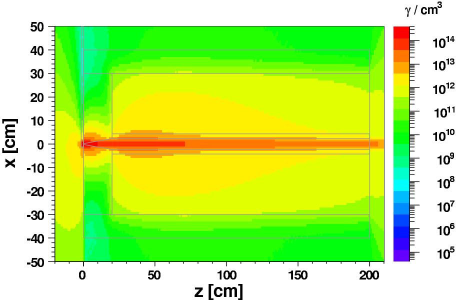


Photon Density

Undulator Based Source (150 GeV)

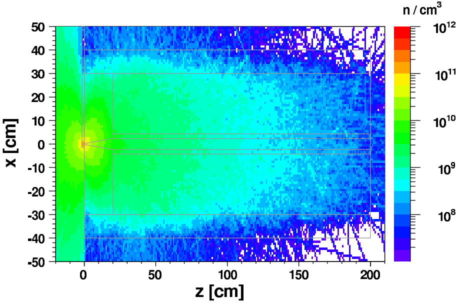


Conventional Source

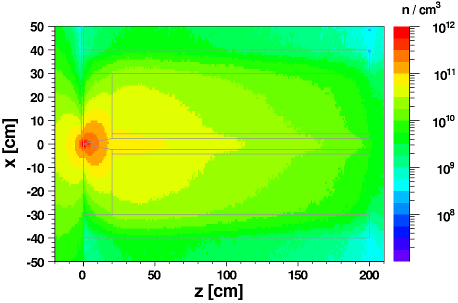


Neutron Density

Undulator Based Source (150 GeV)

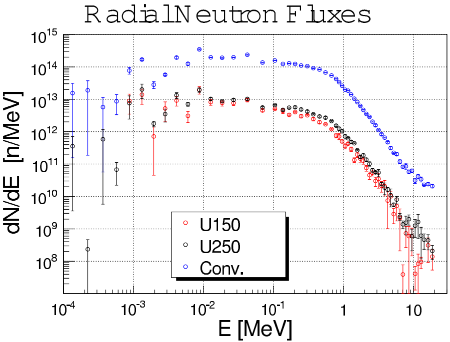


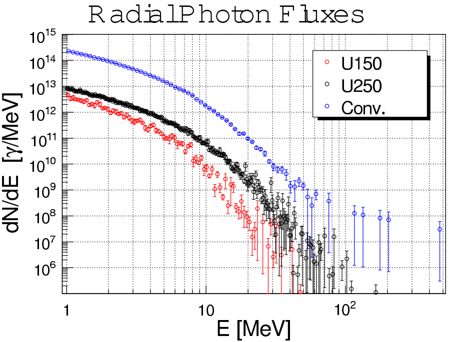
Conventional Source



Neutron and Photon Fluxes

	Area cm^{-2}	Neutrons $[n/(s\ cm^2)]$			Photons $[\gamma/(s\ cm^2)]$		
		U150	U250	Conv.	U150	U250	Conv.
Backw.	3.14E+4	9.03E+8	5.93E+8	4.79E+9	5.11E+09	3.35E+09	3.55E+10
Rad.	1.27E+5	2.15E+7	3.12E+7	7.78E+8	3.20E+07	8.30E+07	2.42E+09
Forw.	3.14E+4	1.34E+7	1.93E+7	6.84E+8	1.13E+12	4.06E+11	1.62E+11
		9.38E+8	6.44E+8	6.25E+9	1.14E+12	4.10E+11	1.99E+11





Source Parts Activation and Dose Rates

Undulator Based Source (150 GeV)

	A_{sat} GBq	A_{5000h} GBq	$\dot{D}_{5000h}$ mSv/h	$\dot{D}_{+1h}$ mSv/h	$\dot{D}_{+1d}$ mSv/h	$\dot{D}_{+1w}$ mSv/h
Target	5288	3421	437	397	213	164
AMD	3689	3566	81	14.0	3.6	0.1
Collimator	1090	1077	21	2.0	0.4	0.1
Solenoid	943	932	2.7	2.2	0.6	<0.1
	11011	8996	542	415	218	164

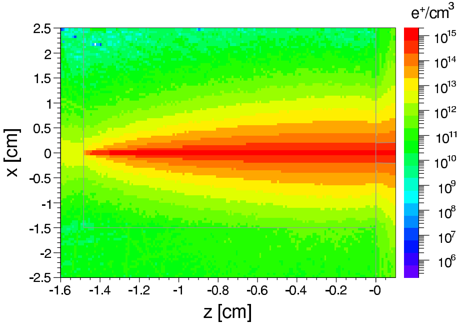
Total Value of Activation and Dose Rate

	A_{5000h} GBq	$\dot{D}_{+1w}$ mSv/h
U150	8996	164
U250	10849	130
Conv.	602850	4007

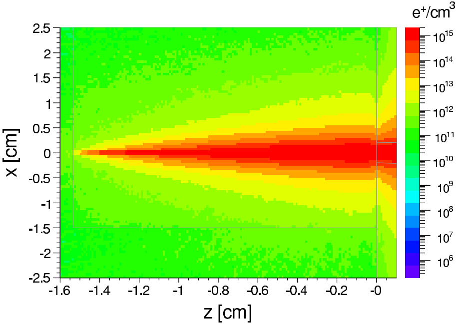
- Reduction of dose rate to level of 0.03 mSv/h is required
- For Ti-alloy target: ^{46}Sc with $T_{1/2} = 84$ d makes 93% contribution in dose rate $\dot{D}_{+1w}$, ^{46}Sc during decay radiates 1.1 MeV photons
- For undulator based source: 90 cm of concrete shielding is required

Positron Shower in Target

Undulator Based Source (150 GeV)

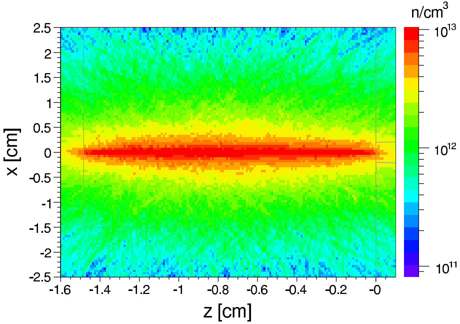


Conventional Source

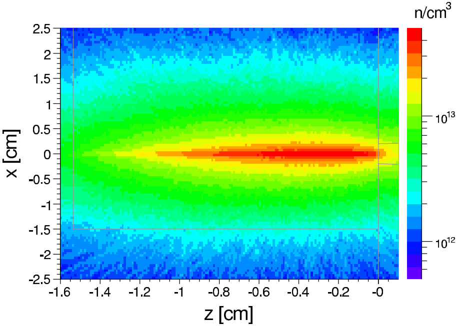


Neutron Density in Target

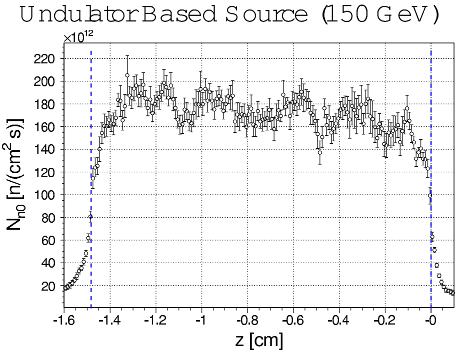
Undulator Based Source (150 GeV)

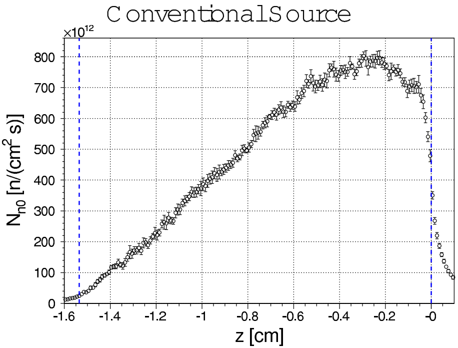


Conventional Source



Neutron Flux along Beam Axis



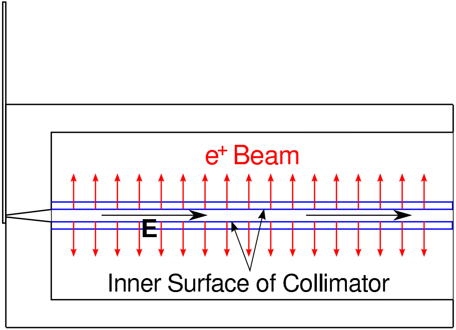


Annual Neutron Fluence F in Target

Source type	U150	Conv.
F_{5000h} for rotationless target, n/m^2	$\simeq 3.6 \cdot 10^{25}$	$\simeq 1.4 \cdot 10^{26}$
F_{5000h} for rotated target, n/m^2 (target is of 38 cm off beam axis)	$\simeq 1.5 \cdot 10^{23}$	$\simeq 6.0 \cdot 10^{23}$
Maximal acceptible fluence, n/m^2	$(2 \div 8) \cdot 10^{24}$	

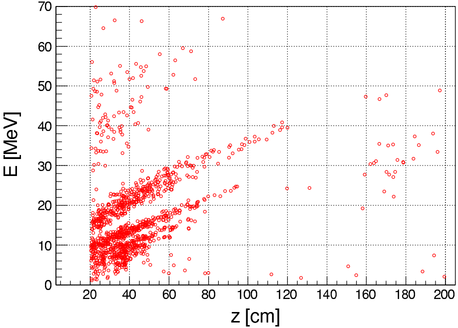
Influence of E-field

- How strong is the influence of acceleration in capture section on deposited energy, activation and etc.?
- Acceleration of positrons has been calculated in ASTRA (K.Flöttmann) for undulator based source (150 GeV)
- Positrons on inner surface of collimator were “transported” in FLUKA

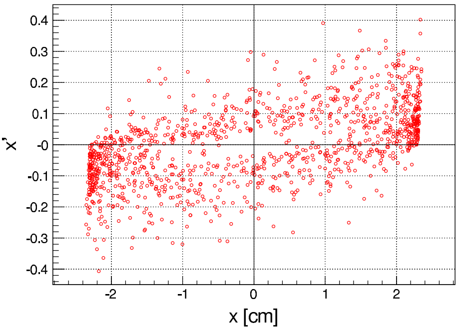


Positrons on inner Surface of Collimator
With Electric Field

Evolution of Positron Energy along Beam Axis

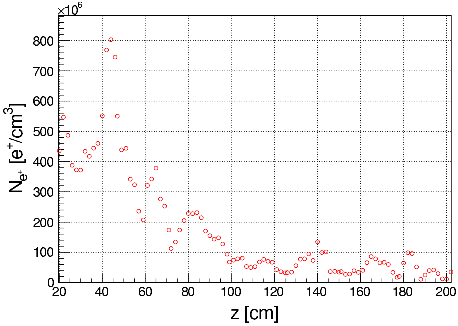


xx′ Positron Phase Space

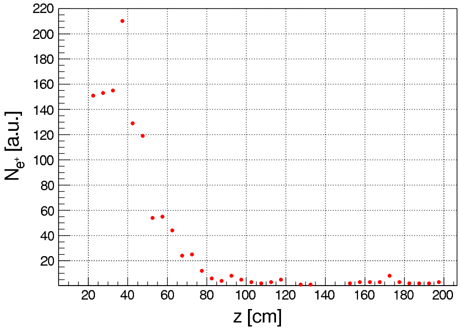


Number of Positrons Crossing the inner Surface of Collimator

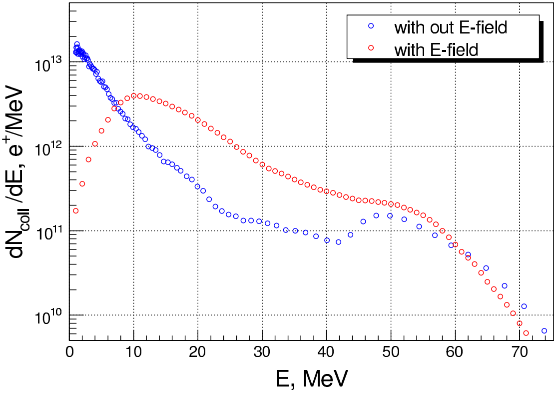
Without Electric Field



With Electric Field



Positron Energy Distribution



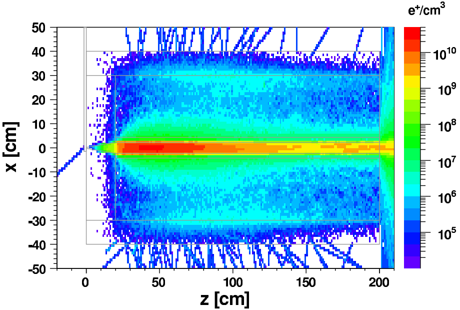
$$N_{e^+} = 6.9 \cdot 10^{13}\ \mathrm{e^+/s}$$

$$\left\langle E^{wo}_{e^+} \right\rangle = 11.6\ \mathrm{MeV}$$

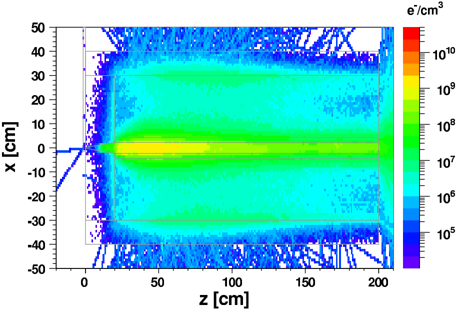
$$\left\langle E^{w}_{e^+} \right\rangle = 17.7\ \mathrm{MeV}$$

Positron and Electron Density

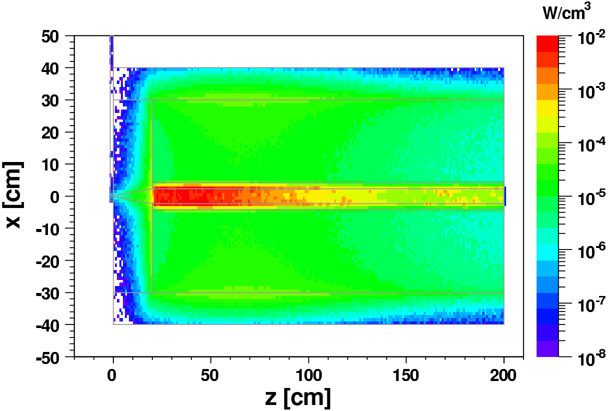
Positron Density



Secondary Electron Density

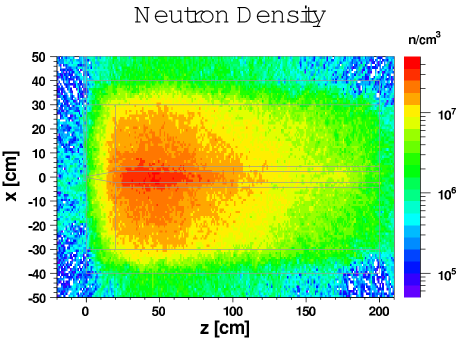


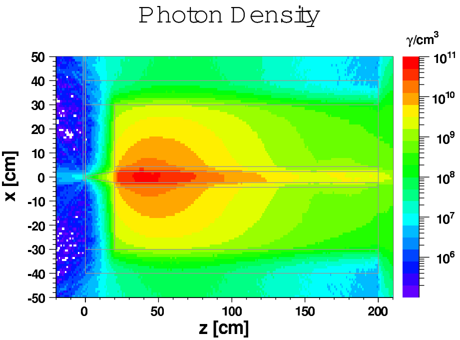
Deposited Energy



	Units	all, w/o **E**		e^+ only, w/o **E**		e^+ only, with **E**	
Target	W	7222	±13.2	–	–	–	–
AMD	W	5138	± 6.1	–	–	–	–
Collimator	W	596	± 2.8	115.4	±6.9	183.8	±0.1
Solenoid	W	62.2	± 0.4	9.2	±1.6	17.0	±0.1

Neutron and Photon Densities





Influence of Electric Field on Neutron and Photon Fluxes

Neutron Flux [n/s]

	all, wo E-field		e^{+} only, with E-field	
Backw.	2.84E+13	±5.2E+11	6.1E+09	±4.1E+08
Rad.	2.72E+12	±6.6E+10	4.6E+10	±9.6E+08
Forw.	4.22E+11	±3.7E+10	8.5E+09	±4.9E+08
	3.15E+13	±6.2E+11	6.0E+10	±1.9E+09

Photon Flux [γ/s]

	all, wo E-field		e^{+} only, with E-field	
Backw.	1.60E+14	±9.9E+11	2.28E+10	±6.7E+08
Rad.	4.06E+12	±9.9E+10	7.99E+11	±1.4E+09
Forw.	3.55E+16	±1.0E+13	1.43E+12	±7.9E+09
	3.57E+16	±1.1E+13	2.25E+12	±1.0E+10

Influence of Electric Field on Source Activation and Dose Rate

Activation A_{5000h} [GBq]

	all, w/o E-field		e^+ only, with E-field	
Target	3421	±114	1.6E-4	±1.2E-4
AMD	3566	±113	2.2	±0.5
Collimator	1077	± 64	54.6	±2.8
Solenoid	932	± 37	16.5	±1.4
	8996	±327	73.2	±4.7

Dose Rate $\dot{D}_{+1w}$ [mSv/h]

	all, w/o E-field		e^+ only, with E-field	
Target	164	±11	–	–
AMD	7.7E-2	±3.1E-2	1.1E-6	±2.8E-7
Collimator	7.8E-2	±3.9E-2	4.2E-3	±1.8E-3
Solenoid	7.7E-4	±7.5E-4	3.3E-6	±3.1E-7
	164	±11	4.2E-3	±1.8E-3

Summary

- FLUKA calculations for the undulator based and conventional positron sources have been performed
- Neutron fluxes, source parts activation and dose rates have been studied
- Influence of positron acceleration in capture section has been estimated